EXCITATION SPECTROSCOPY AS A TOOL OF MICROELECTRONICS RELIBAILITY

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Purpose

The main objective of this task was to experimentally determine the feasibility of using a non-contact IR emission spectroscopy technique to measure the hot spot channel temperature of sub-micron GaAs metal semiconductor field effect transistor gate during operation.

Presentation outline

1. Electron-phonon/exciton interaction-theory
2. Impurity emission spectrum
3. AlGaAs MESFET
4. Temperature dependence
5. Optical probing system
6. Results
7. Conclusions

Energy shift by the electron-phonon interaction

$\delta E_i = \sum_j (\langle i | H' | j\rangle \ \langle j | H' | i\rangle) / (E_i - E_j) + \langle i | H'' | j\rangle$,

Where

$\langle i |$ ($\langle j |$) and E_I (E_{jb}) are the initial (intermediate) quantum states and energy levels,

$H' = iV_1 \sum_q (h\omega_q / 4\pi M v^2)^{1/2} (b_q - b_q^+)$,

$H'' = - V_2 (h / 4\pi M v^2) \sum_{qq'} (\omega_q \omega_{q'}) (b_q - b_q^+) * (b_{q'} - b_{q'}^+)$

Hamiltonian of electron-phonon interaction

$H = H_{latt} + H_{ion,exc} + H_{int,}$

Where

$H_{latt} = \sum_k (h\omega_k)^{1/2} (a_k a_k^+ + 1),$

$H_{ion,exc} = H_o + H_{cryst} + H_{so,}$

$H_{int} = V_1\varepsilon + V_2 \varepsilon^2 + \ldots..,$

$\varepsilon = iV_1 \sum_q (h\omega_q /4\pi Mv^2)^{1/2} (b_q - b_q^+),$

H: Ion-vibration interaction Hamiltonian,

h: Plank's constant,

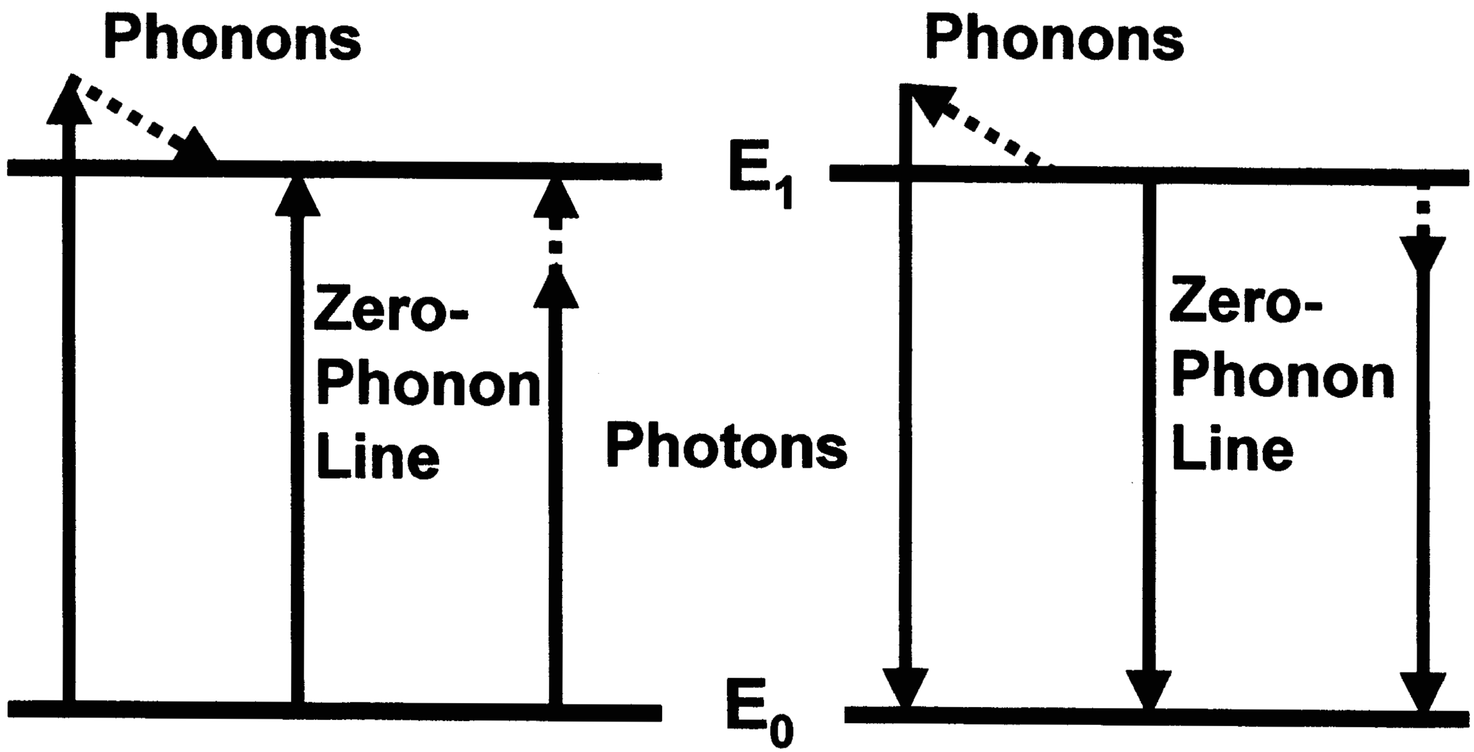
$V_{1,} V_2$: Interaction matrix constants,

$\omega_{k,} \omega_q$: Photon and phonon frequency,

M, v: Mass and velocity of the electron,

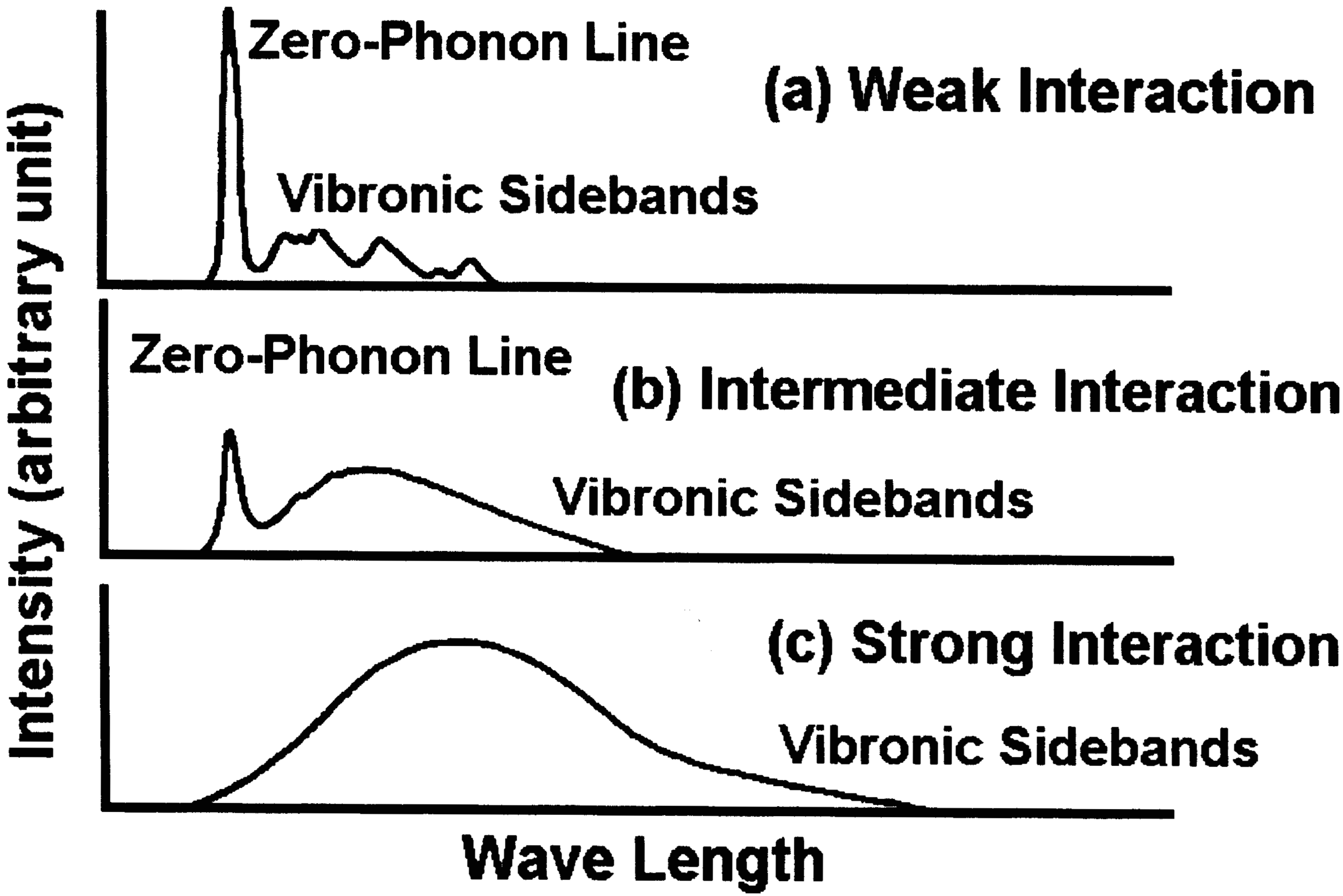
$a_{k,} b_q$, ; a_k^+, b_q^+: Annihilation and creation operators of photons and phonons

Electron-Phonon/Exciton Interaction

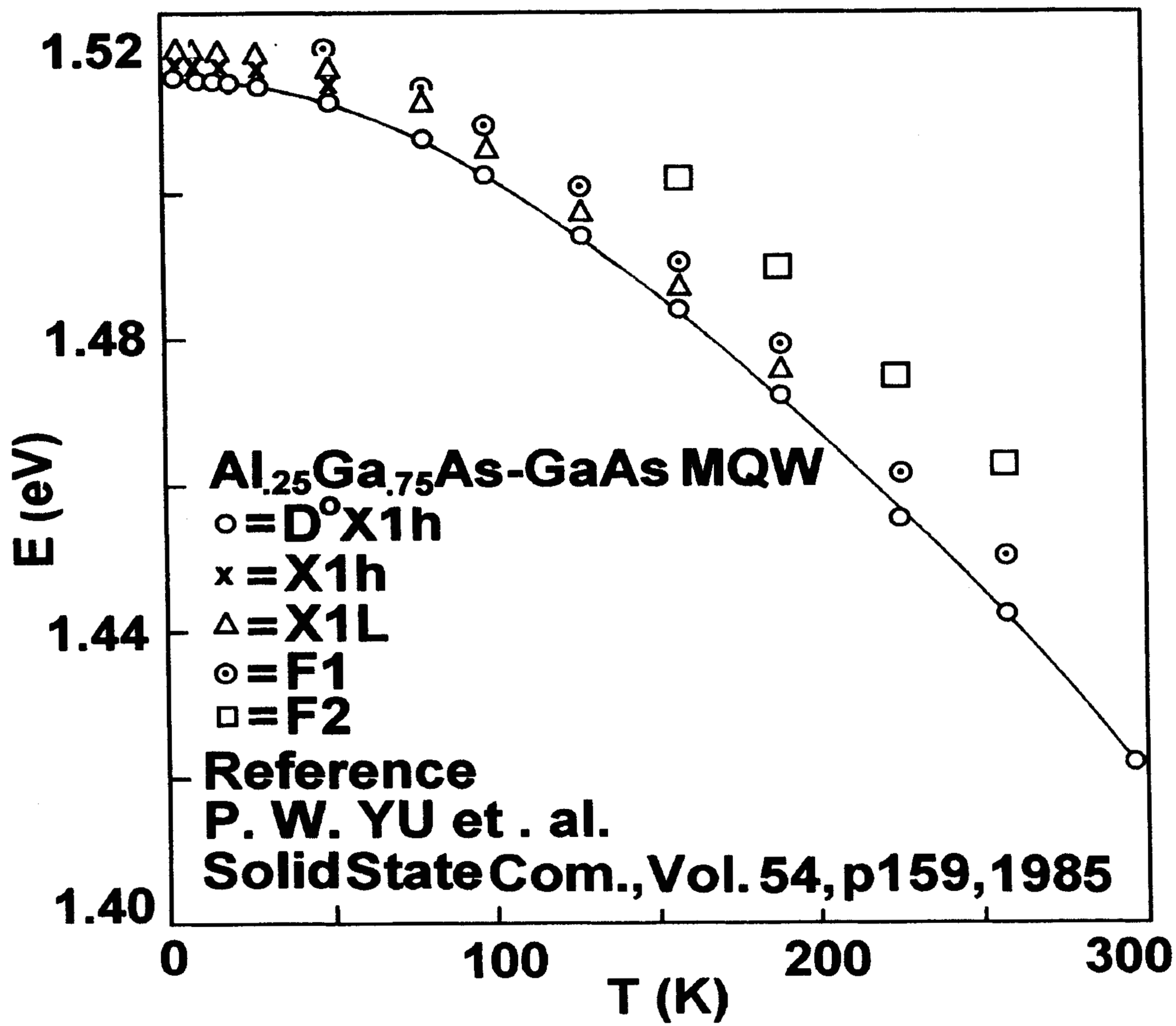


(a) Absorption (b) Emission

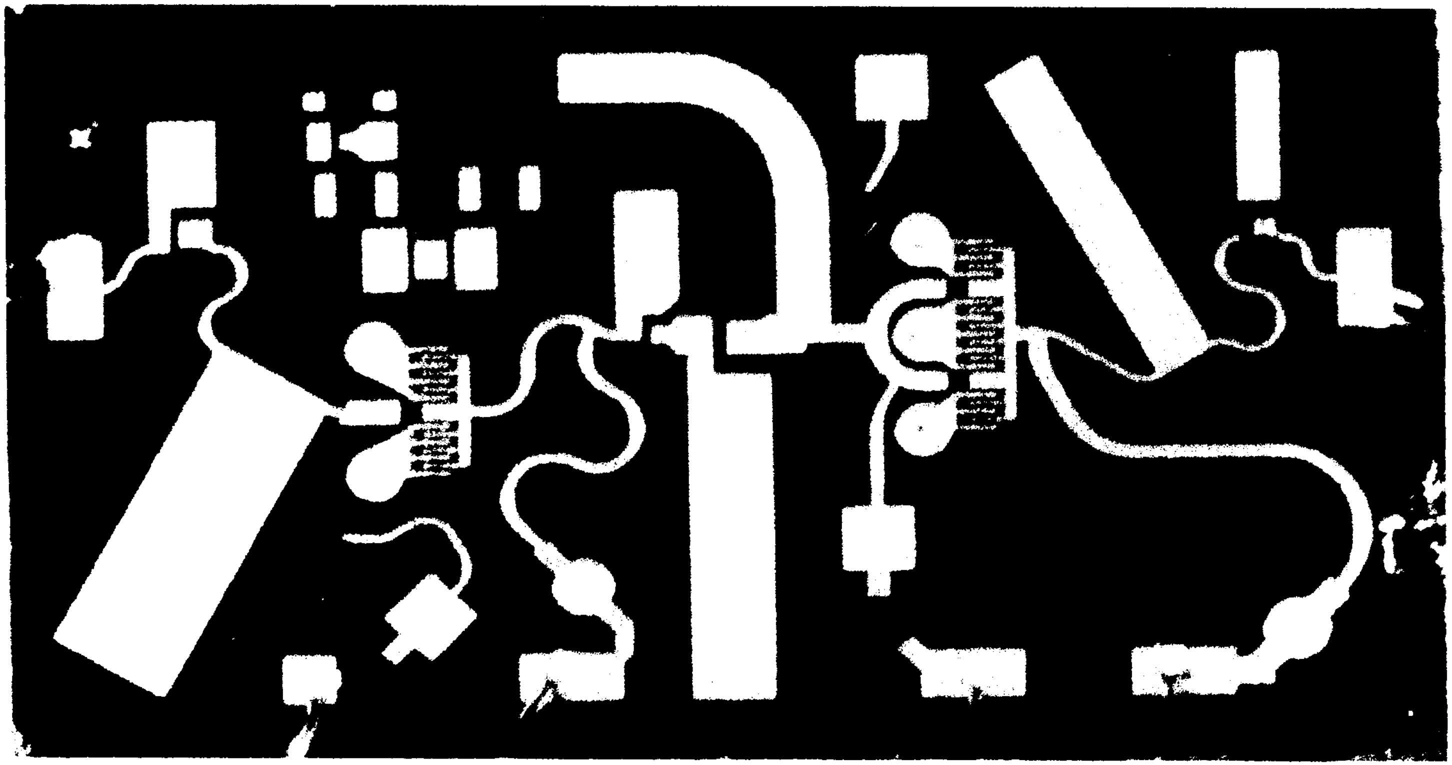
Three types of interaction profiles



Temperature dependence of the bandgap

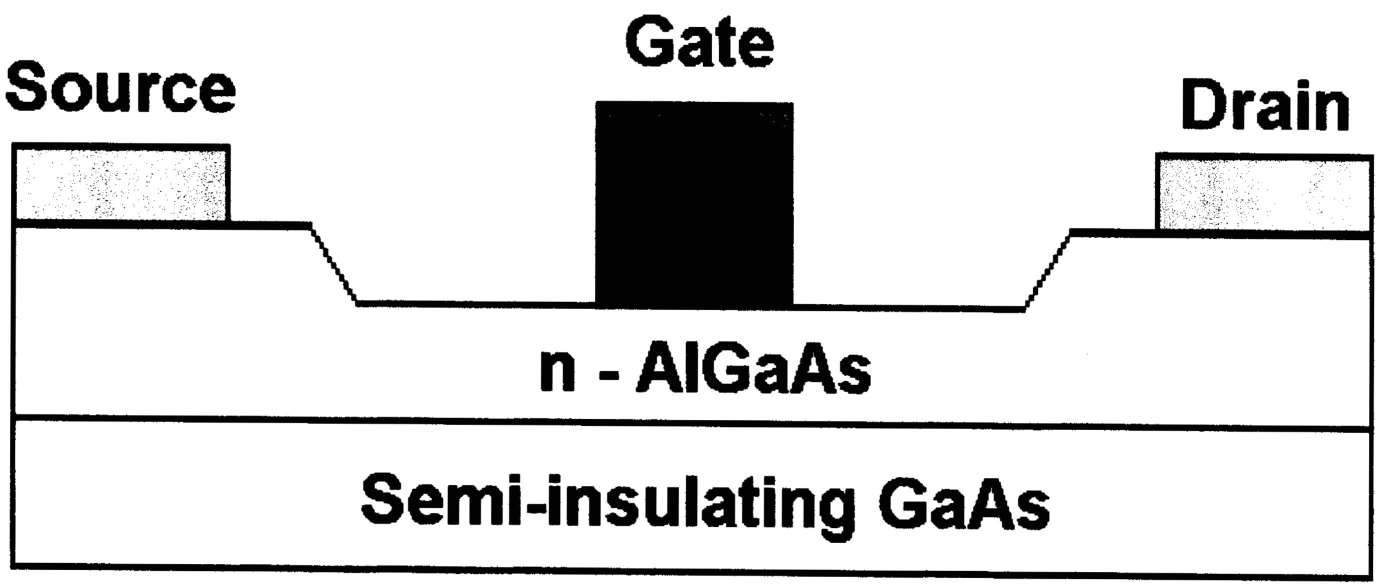


AlGaAs MESFET



A commercially available GaAs MESFET, with gate width of less than 0.5 micron.

AlGaAs/GaAs heterostructure FET



Impurity emission spectrum: theory

$$Ecv(T) - Ecv(To) = -\alpha(T + \beta)$$

where T: Channel Temperature in Kelvin

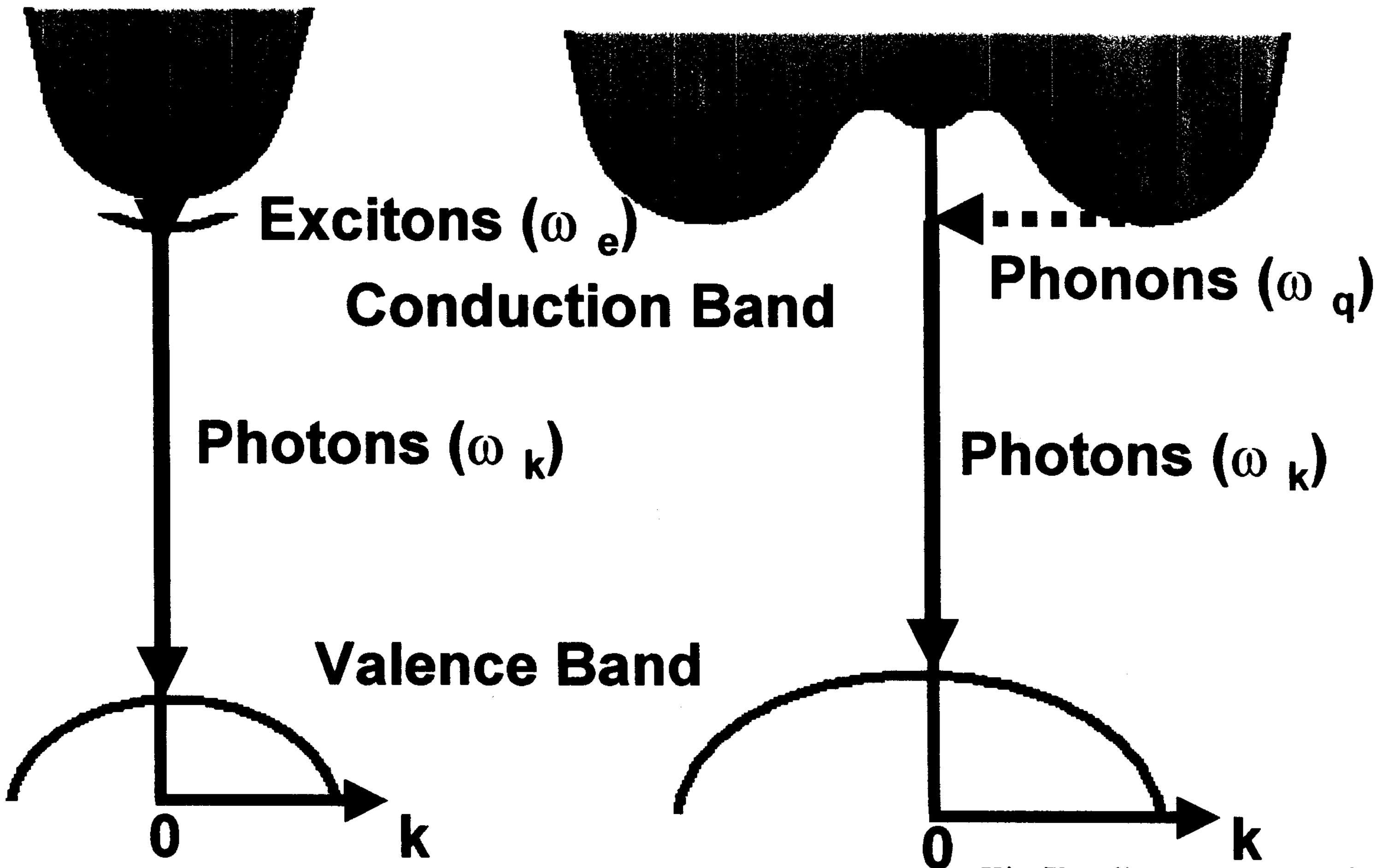
To: Operating Temperature

Ecv: Energy Band-gap

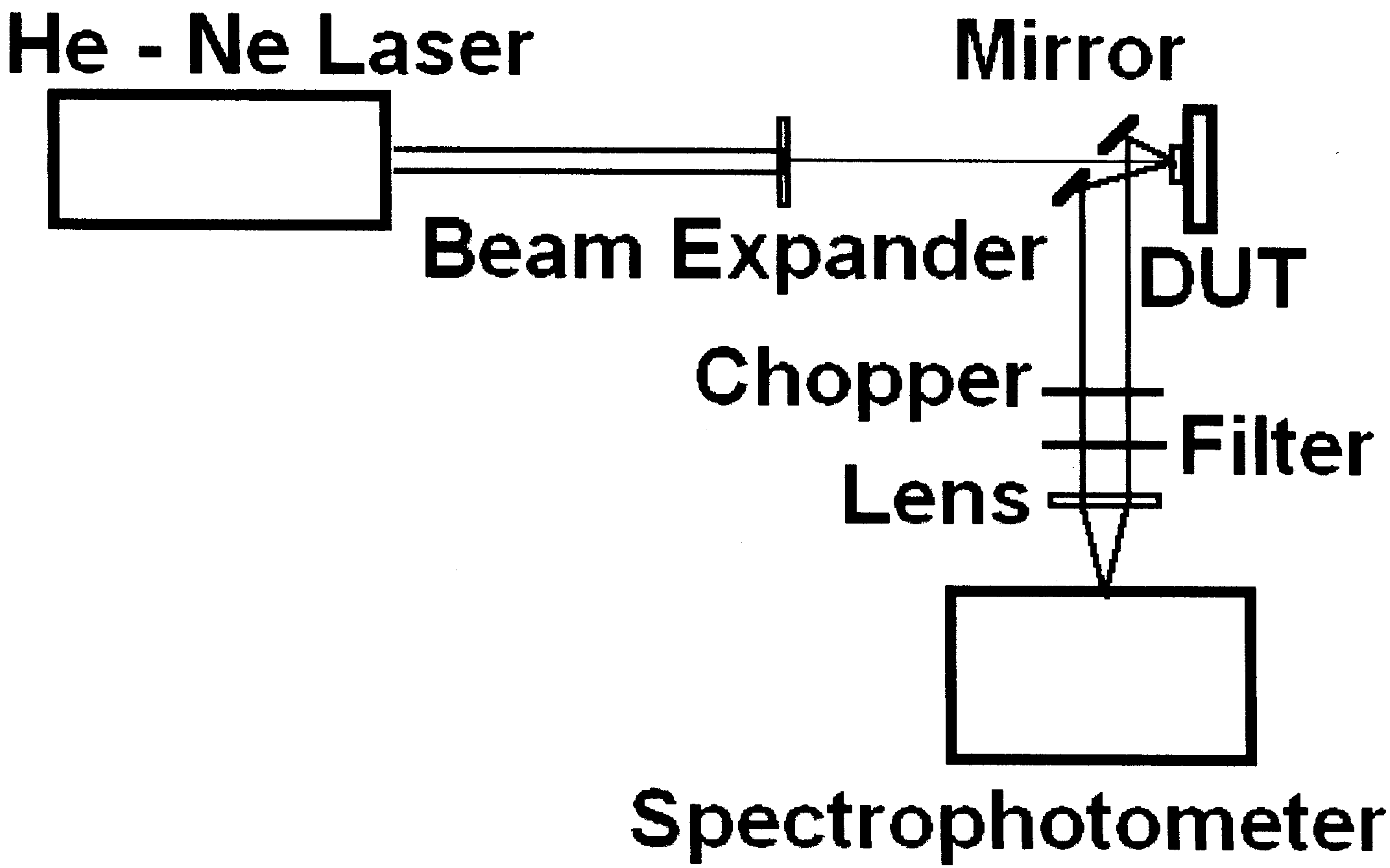
α: Slope of the extended plot (Fitting Parameter)

β: Debye Temperature (Fitting Parameter)

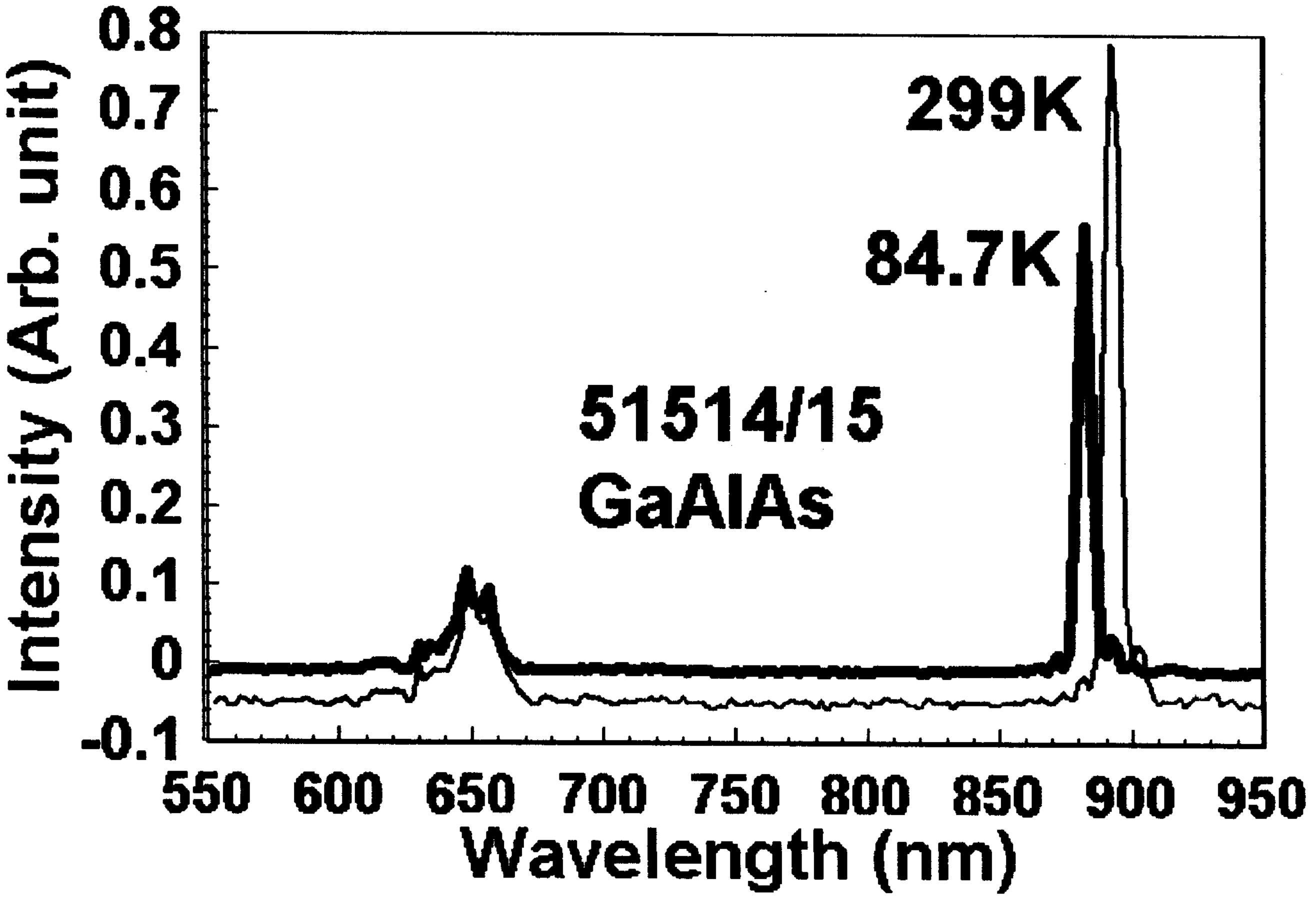
Temperature dependence of emission spectrum



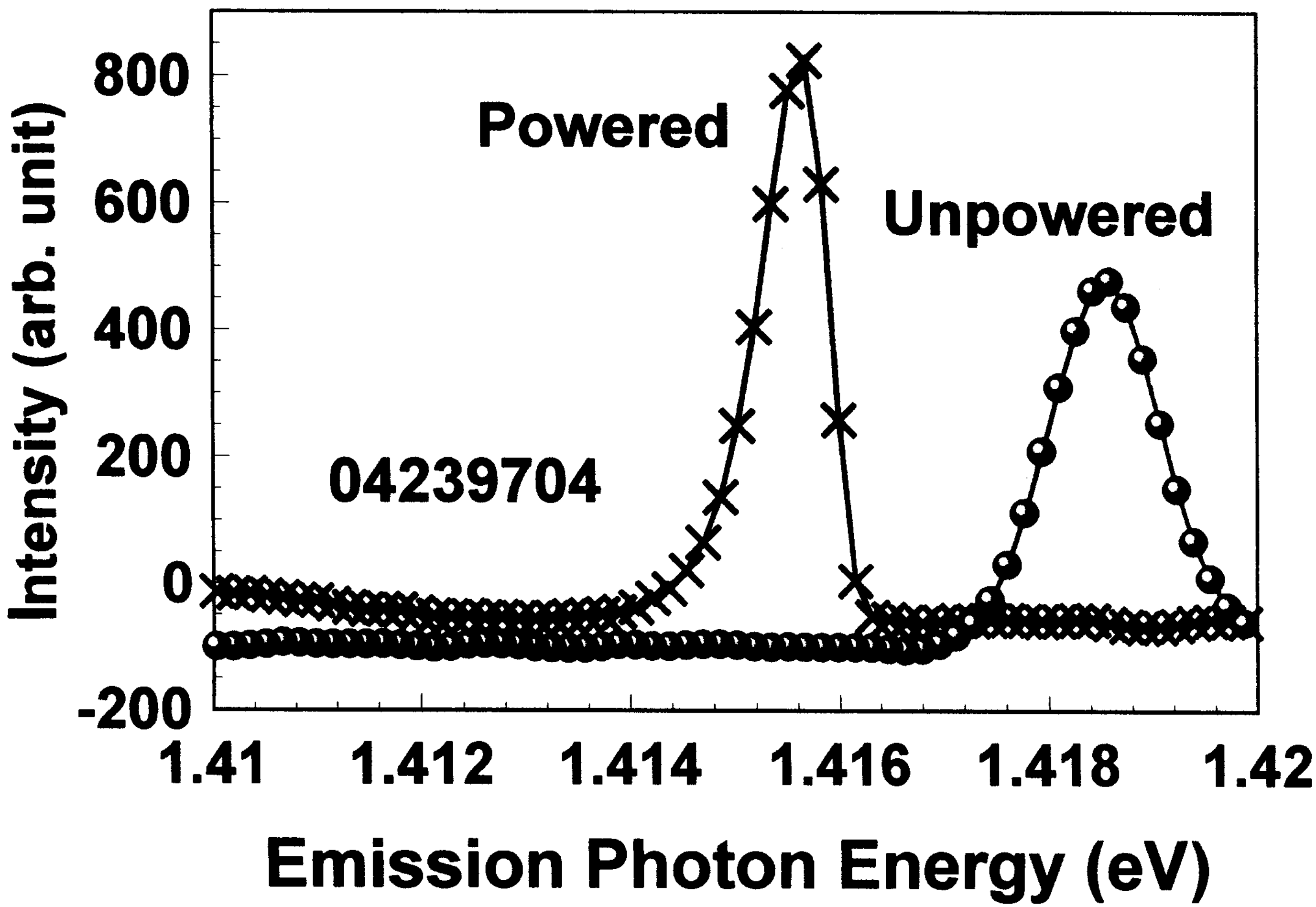
Optical probing system



Typical emission spectrum of the AlGaAs MESFET gate



Impurity emission spectrum: experiment



Summary of band shift data

Test Temperature	Band Position (eV)	Power Applied
299.1K	1.41373	No
84.8 K	1.42265	Yes
84.8 K	1.43003	No

Gate temperature rise

$$
\begin{aligned}
dT &= T - T_o \\
&= (25.9\ ^{o}C + 188.4\ ^{o}C) \\
&\quad \times (871.5 - 867.0)/(877.0 - 867.0) \\
&= 96.4\ ^{o}C.
\end{aligned}
$$

Discussions

- A non-destructive, submicron-size spot laser beam
- A GaAs MESFET under various operating condition0.5 μm and a spectral resolution of about 0.1 Å
- 30-200 times finer spatial resolution (15 μm) than can be obtained using the best passive IR systems available
- Temperature resolution (< 0.01 K/ μm) of this technique is depend upon the spectrometer used, and that it can be improved further.

Significance of the results

Lifetime estimation of power devices in space application, such as GaAs MESFETs, depends closely upon the operating temperature of the sub-micron size power MESFET channel. Currently, the only commercially available non-contact technique to characterize the thermal distribution of the powered device is passive infrared sensing. However, this method does not measure the true local gate temperature and the resolution is limited to 15 μm, which is inadequate for state-of-the-art devices with gate structures less than one micron.

Conclusions

The information obtained from this technique can be used to estimate device lifetimes for critical applications in long term space missions and for measurements of channel temperature of devices under actual operating conditions. Another potential use of the novel technique can be as a cost-effective prescreening tool for determining the "hot spot" channel temperature of devices under normal operating conditions which can further improve device design, yield enhancement, and reliable operation.